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A DESKTOP PROCEDURE FOR MEASURING THE TRANSMISSION LOSS OF AUTOMOTIVE DOOR SEALS

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Purdue University



Increasing concern with acoustic environment within a vehicle


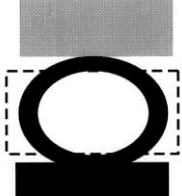

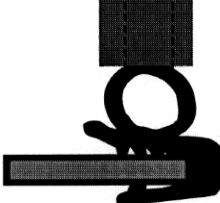

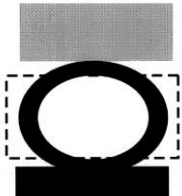
- Previous methods to measure acoustic properties require large scale facilities which are expensive.
- Objective here is to develop a simpler and more economical desktop procedure to allow easy and fast acoustic measurement of automotive door seals.
- Procedure described here mainly adapted from four-mic measurement method (E2611 ASTM International, 2009).




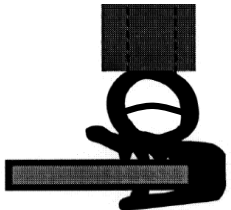

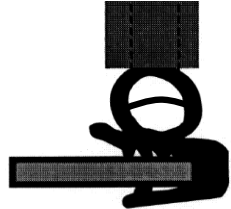
Seal Descriptions

- Come in many forms

Primary Bulb Seals

Seals	Characteristics	Clamp method
	<ul style="list-style-type: none"> • Designed to have only one air cavity • No vent holes 	
		
		

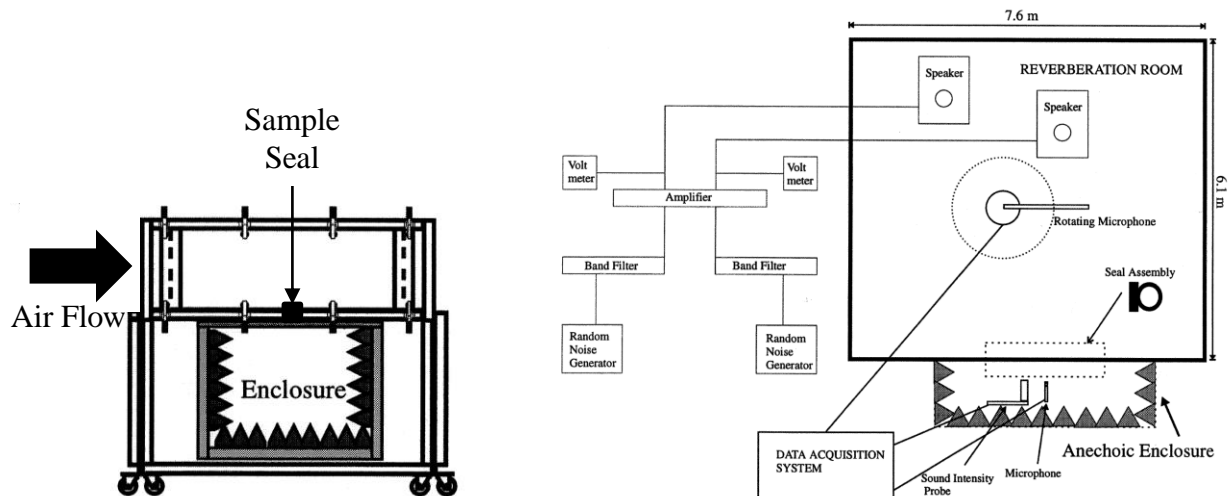
Multiple Chamber Seals

Seals	Characteristics	Clamp method
	<ul style="list-style-type: none"> • Designed to have two or more air cavities • No vent holes 	
		

Previous Work

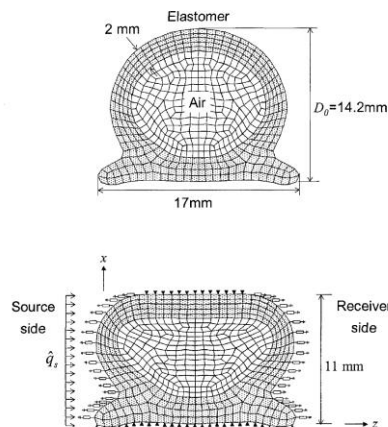
Robert J. Danforth III and Luc Mongeau, “Sound transmission through road vehicle primary bulb seal assemblies,” HL 96-14 Report #3086-2, December 1996

- Experiments using a **small quiet wind tunnel**, bulb seals excited by aerodynamic pressure.
- Sound pressure transmitted into enclosure measured for varying flow velocities, cavity dimensions, and other parameters.
- Noise reduction measurements performed using **reverberation room** – effect of compression.



Junhong Park and Luc Mongeau, “Effects of mechanical properties of sealing systems on aerodynamic noise generation inside vehicles,” HL 2002-1 May 2002

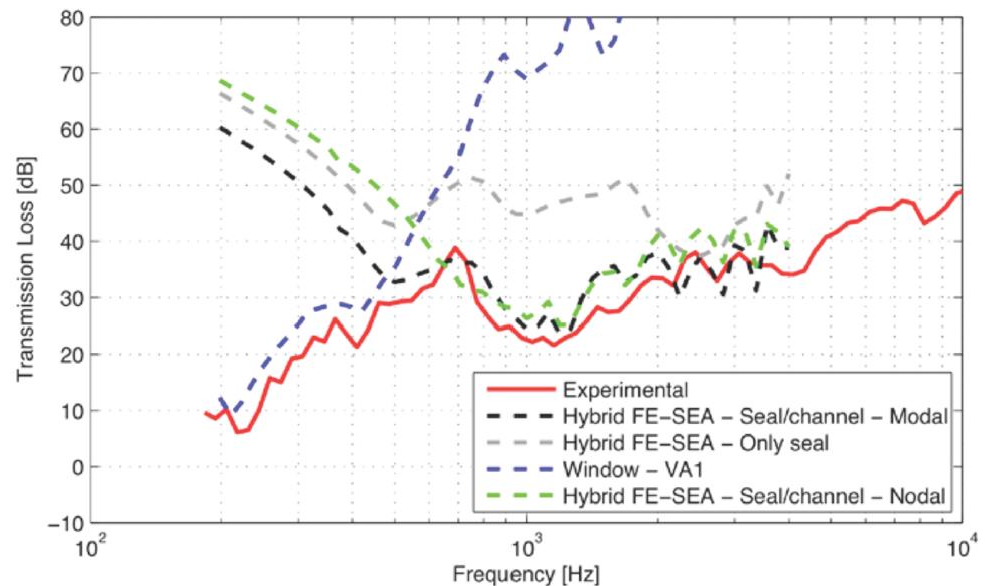
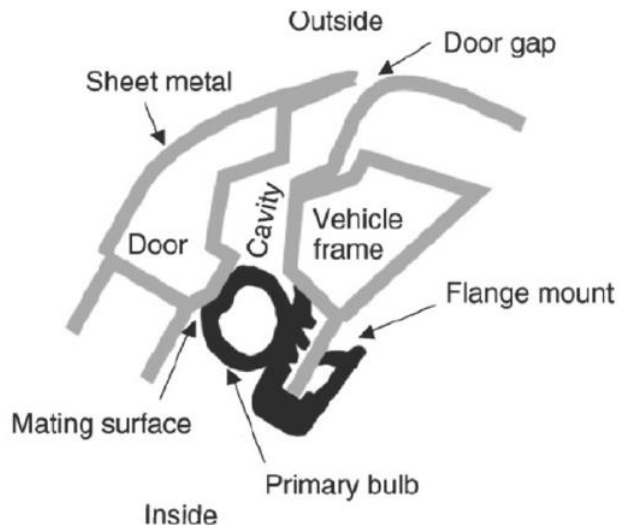
- Numerical analysis of sound transmission through a bulb seal was done using the finite element method.
- This allows the complex geometry of a bulb seal as well as its boundary conditions to be taken into consideration.
- Effects of seal mechanical properties on interior aerodynamic noise were investigated. Seals made of EPDM and TPE were experimented using the reverberation room test method.



Previous Work

Julio A. Cordioli et al., “Application of the Hybrid FE-SEA Method to Predict Sound Transmission Through Complex Sealing Systems,” SAE International 2011-01-1708, May 2011

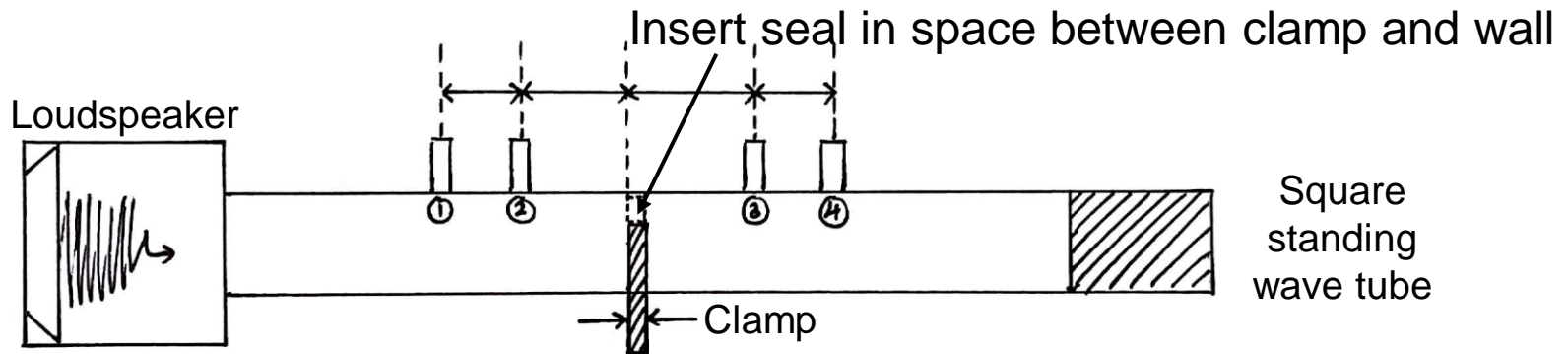
- Presented a numerical validation of Hybrid FE-SEA model
- Door components mounted in reverberation room aperture
- Transmitted sound level measured with and without seal in place.
- Typical STL about 30 dB.



Goal: To create a desktop procedure as a simple alternative to previous measurement methods

- Measurement Procedure and Apparatus
- Correction Procedure – to compensate for effects of clamp
- Seals Tested
- Transmission Loss and Effect of Compression

4-Mic Procedure (E2611 ASTM International, 2009)



- Estimate transfer matrix elements:

- Transmission Coefficient

$$T_a = \frac{2e^{jkd}}{T_{11} + \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}}$$

- Transmission Loss

$$TL = 20 \log_{10} \frac{1}{|T_a|}$$

- Measure **combined transmission loss of seal and clamp** by using two load method

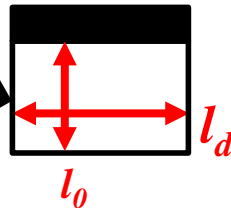
Experimental Apparatus

Apparatus used in the experiment

- Automotive door seals cut to the width of the standing wave tube (6.35 cm)
- 6.35 cm x 6.35 cm square standing wave tube



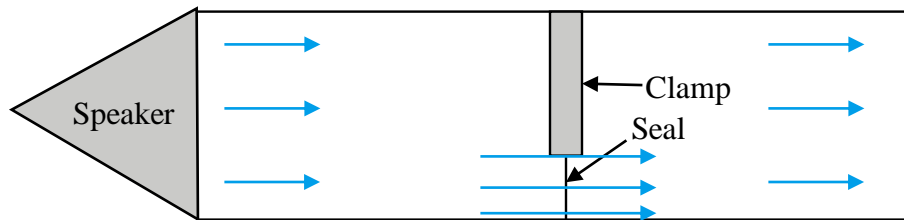
- Seal of width l_d inserted in opening and compressed to varying degrees by changing l_0 .



- Upper frequency limit of 2700 Hz due to tube dimensions – smaller tube could be used to increase upper frequency limit.

Correction Factor Calculation

As the seal only takes up part of the standing wave tube, the measured transmission loss includes the contribution of the metal clamp (assumed to have infinite TL).



- Transmission loss measured is a combination of the seal and clamp, but the desired results is the **transmission loss of the seal itself**.
- A correction factor is needed to account for the **area change** and **inertial-nearfield effects**.
- Determine latter factor experimentally by measuring transmission loss of materials **having known properties**.

Correction Factor Calculation

Correction procedure:

- A separate series of experiments were conducted using **three** “reference” materials: a **lightweight, fibrous material**, a **polyurethane foam**, and **air** filling the space between the clamp and the tube wall.
- Samples were cut into pieces ranging from 1.00 cm to 6.35 cm in width with an increment of 0.50 cm.
- Similar procedure for the main experiment was then used with the individual samples.
- Measured transmission loss of full width (6.35 cm) sample, then represents “known” transmission loss of material.
- Find correction factor necessary to cause small sample results to agree with full width results.



White fibrous material used in correction factor estimation

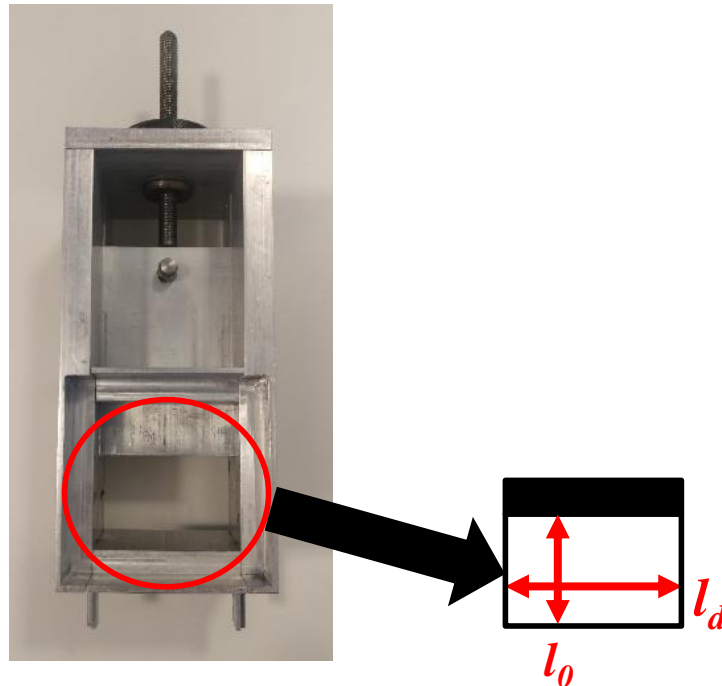
Area Correction Factor Calculation

Area correction:

- The transmission coefficient is first adjusted to compensate for the area change

$$T_{new} = T_{original} \times \frac{l_d}{l_0}$$

where $T_{original}$ is the transmission coefficient of the combined system, l_d is the width of the sample and l_0 being the width of the duct.



Inertial-Nearfield Correction Factor Calculation

- After obtaining the area-adjusted transmission coefficient, the inertial-correction factor at all different frequencies can be calculated via the following formula:

$$\alpha \left(\frac{l_0}{l_d}, \omega \right) = \frac{T_{new,duct}}{T_{new}}$$

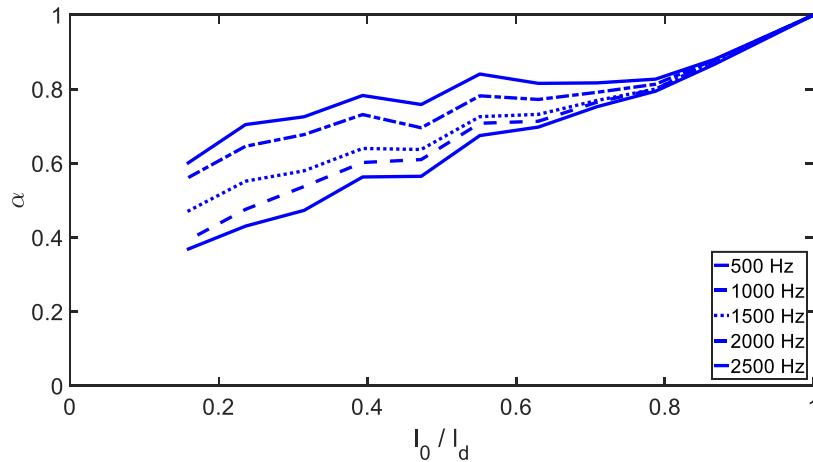
where $T_{new,duct}$ is the known transmission coefficient of the full width sample.

- The correction factors for three different material cases were averaged to give a single $\alpha \left(\frac{l_0}{l_d}, \omega \right)$.
- At each frequency, a polynomial was fitted to the result to obtain the following formula for the inertial-correction factor:

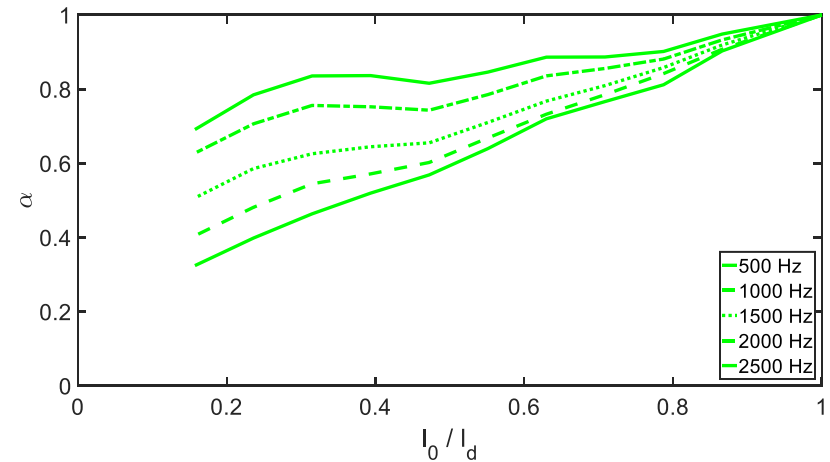
$$\alpha \left(\frac{l_0}{l_d}, \omega \right) = a_1 \left(\frac{l_0}{l_d} \right)^2 + a_2 \left(\frac{l_0}{l_d} \right) + a_3$$

Measured Inertial-Nearfield Correction Factor

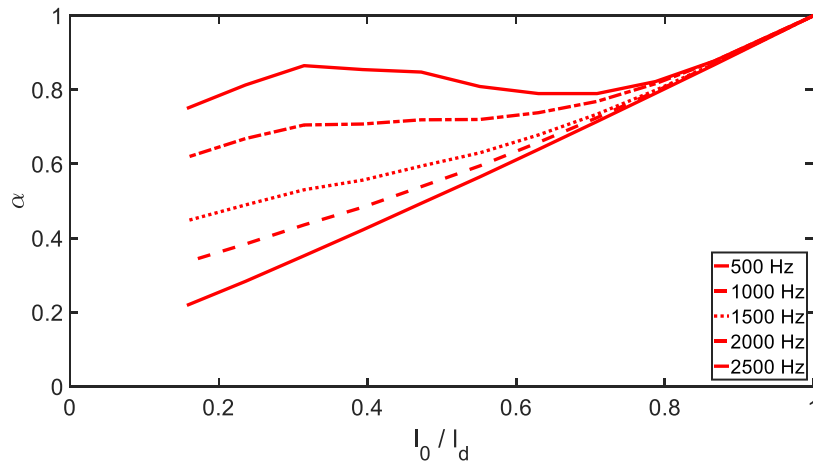
Correction factor for the white fibrous material



Correction factor for the green foam material



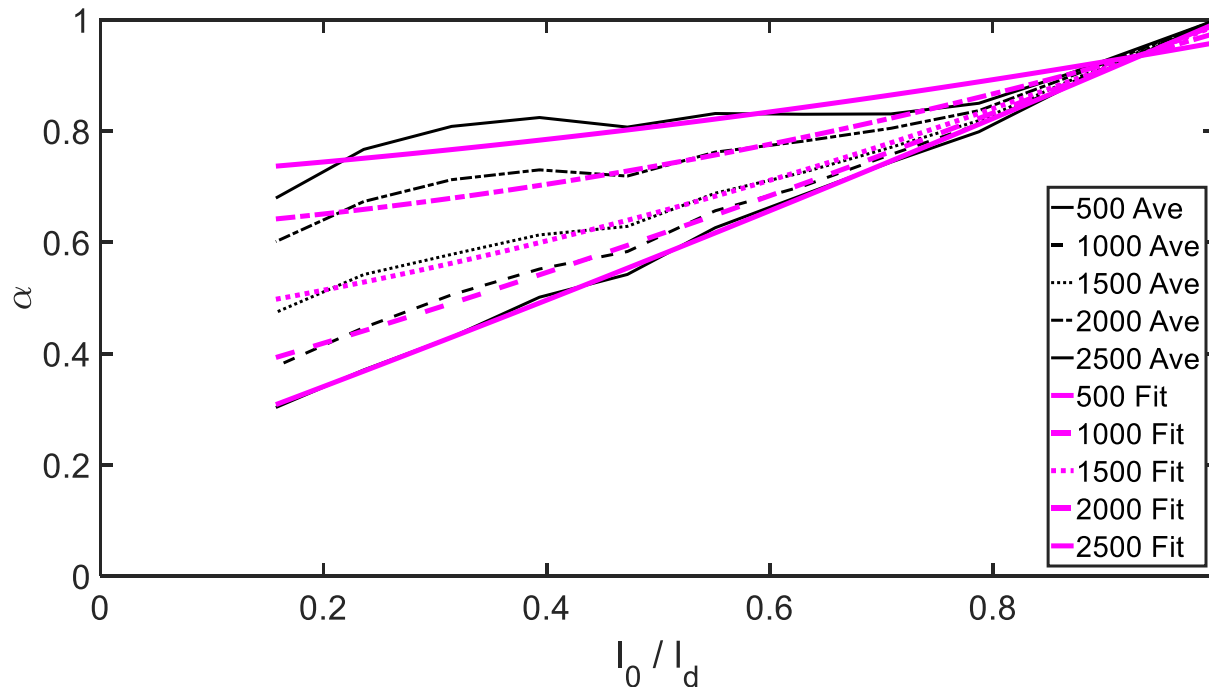
Correction factor for the layer of air



- Inertial nearfield is larger at low frequencies and for small openings as expected
- Correction factor goes to unity as sample size approaches full duct width

Inertial-Nearfield Correction Factor

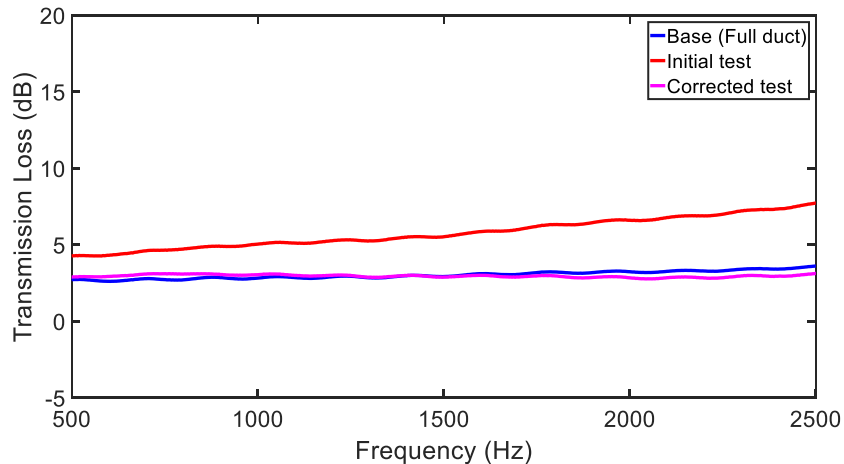
Average correction factor with polynomial fit: five examples



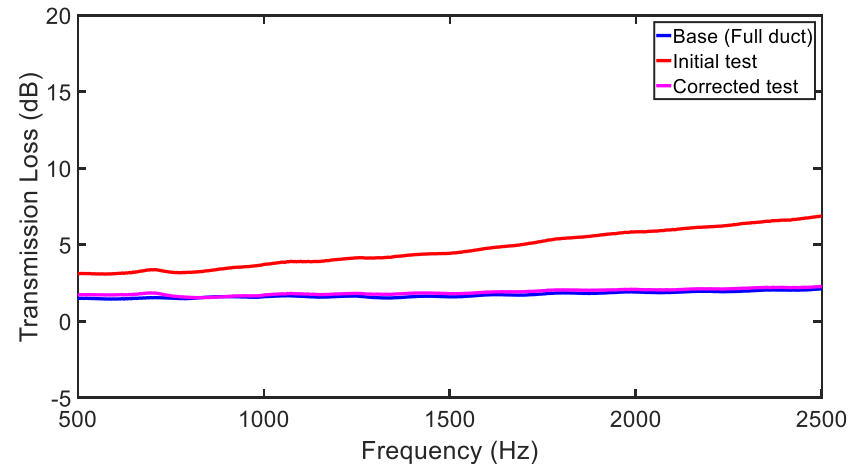
- Correction is most significant for small values of (l_0/l_d) (i.e., large contraction) and low frequencies.
- Under those conditions, inertial-nearfield effect is important.

Correction Factor Implementation (Verifications)

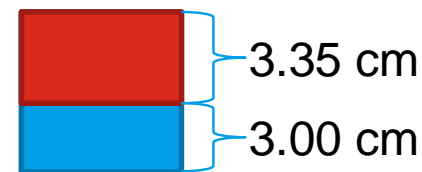
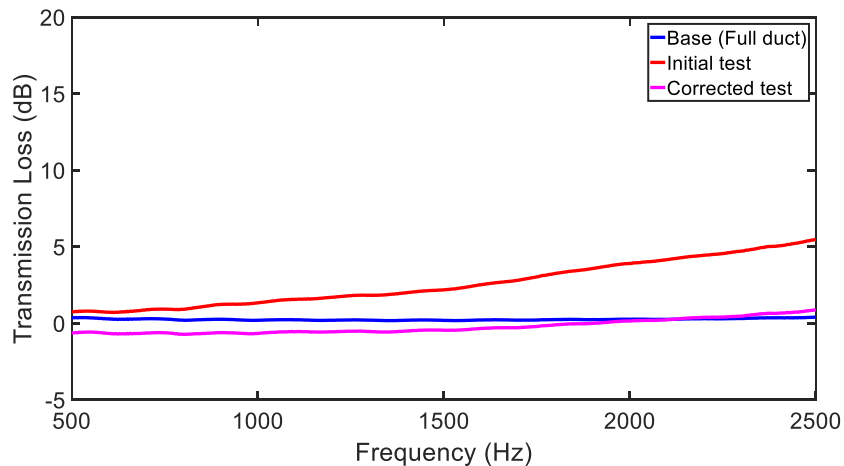
White fibrous material (3.0 cm)



Green foam material (3.0 cm)



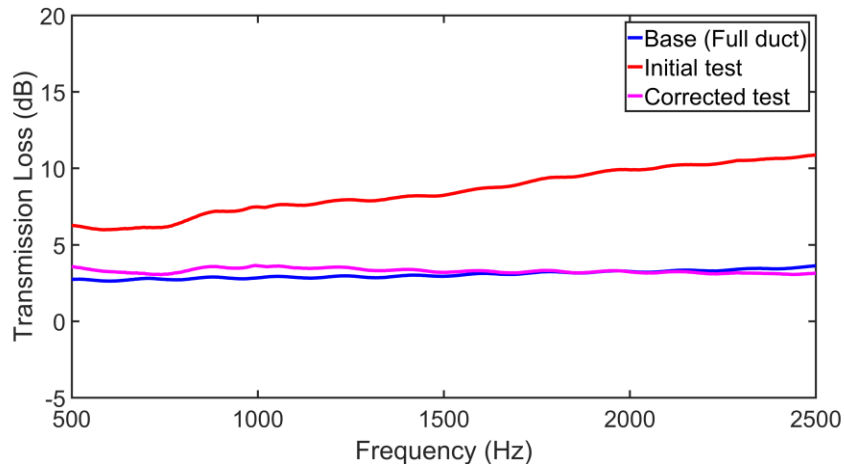
Layer of air (3.0 cm)



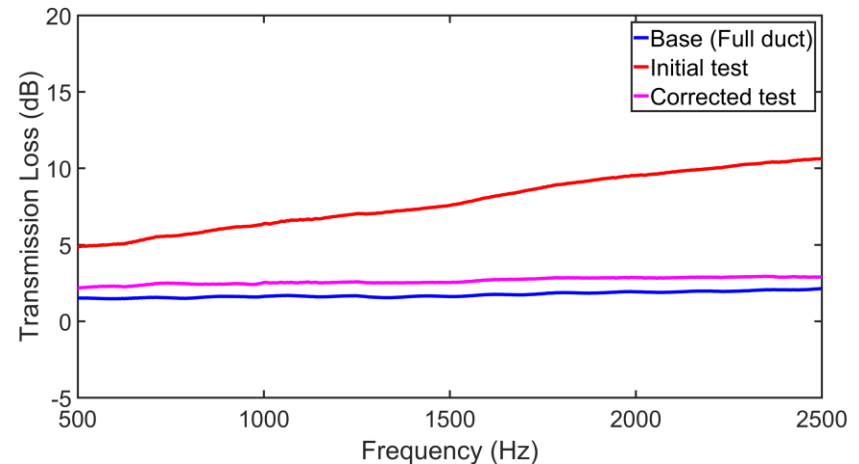
- Measured transmission losses successfully “corrected” to known “true values”

Correction Factor Implementation (Verifications)

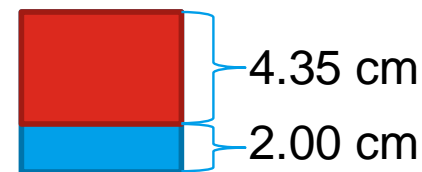
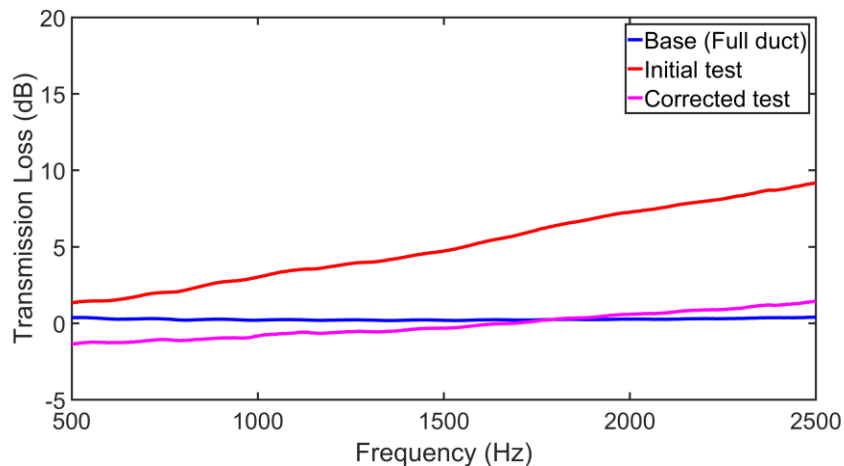
White fibrous material (2.0 cm)



Green foam material (2.0 cm)



Layer of air (2.0 cm)



- Measured transmission losses successfully “corrected” to known “true” values

After clamping the seals, experimental procedure was as follows:

- White noise ranging from 0 Hz to 2700 Hz was generated with sound pressure measured at the respective standing wave tube locations with Bruel and Kjaer microphones.
- Measurements made with two terminations.
- Samples were tested ten times at each compression level.
- Data collected was processed through MATLAB where the transmission coefficient of the different seals were calculated using the two correction factors obtained from before:


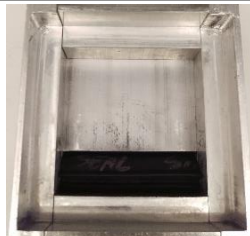

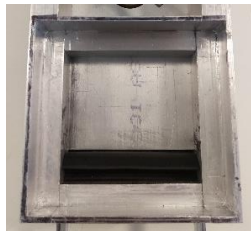

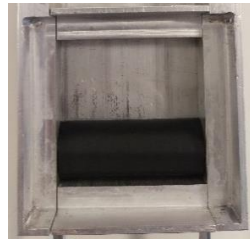




$$T_{seal,new} = T_{original} \times \frac{l_d}{l_0} \quad (\text{Area correction})$$

$$T_{seal} = \alpha\left(\frac{l_0}{l_d}, \omega\right) \times T_{seal,new} \quad (\text{Inertial Nearfield correction})$$

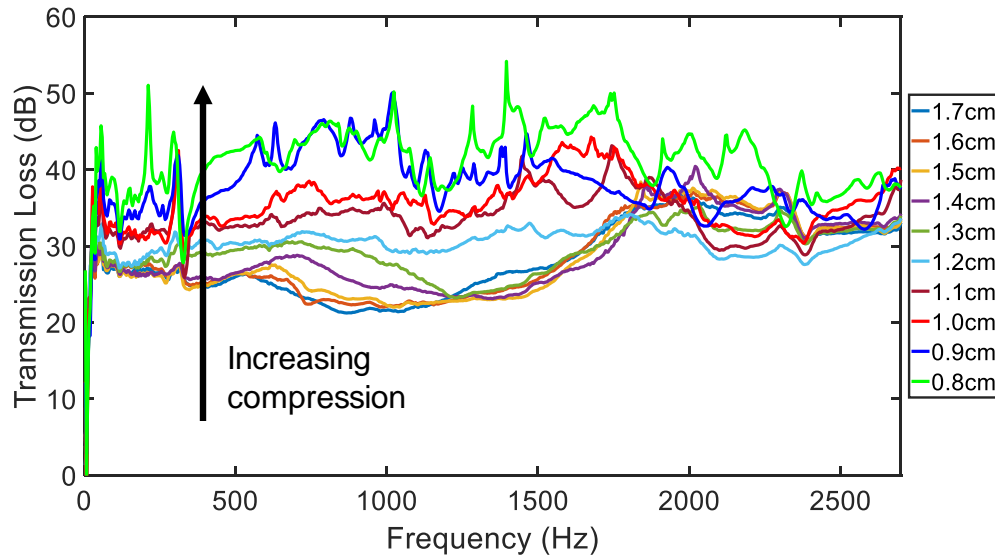
$$TL_{seal} = 20 \log_{10} \frac{1}{|T_{seal}|}$$

Type of Seals Tested

Five different seals were tested in the development of this procedure, at varying degrees of compression.

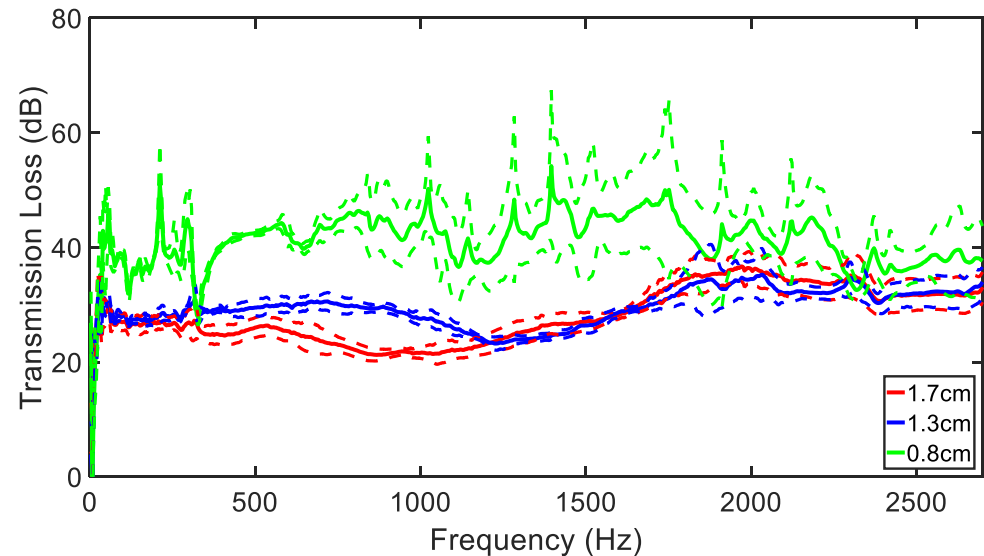
Seals	Seal only	Clamped	Seals	Seal only	Clamped
A (1.7 – 0.8 cm) (Primary)			D (1.2 – 0.8 cm) (Primary)		
B (2.4 – 1.5 cm) (Primary)			E (3.9 – 3.0 cm) (Multi chamber)		
C (3.6 – 2.7 cm) (Multi chamber)					

Corrected average transmission loss for seal A with standard deviations from 10 trials at each compression

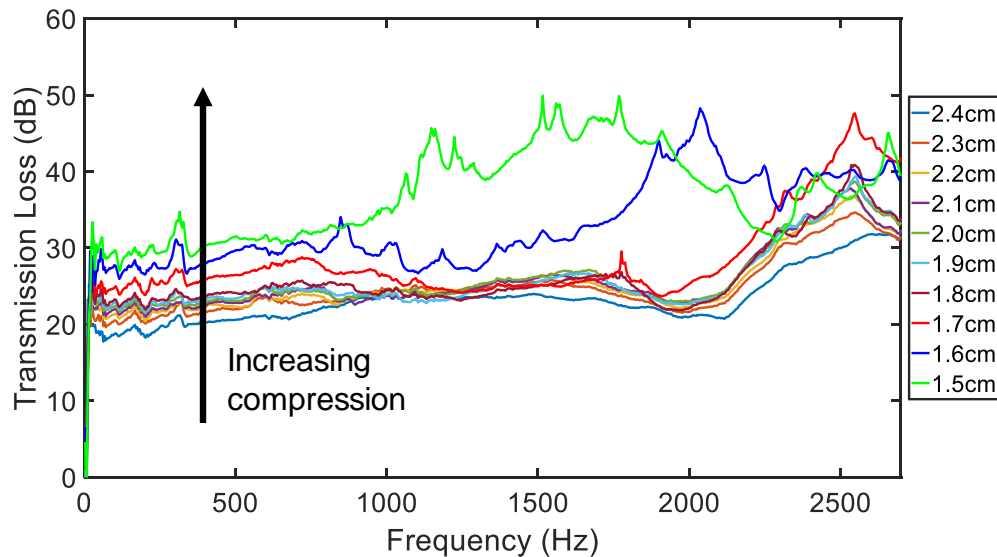


Seal A

- Essentially monotonic increase of TL with compression
- Scatter increases as compression increases

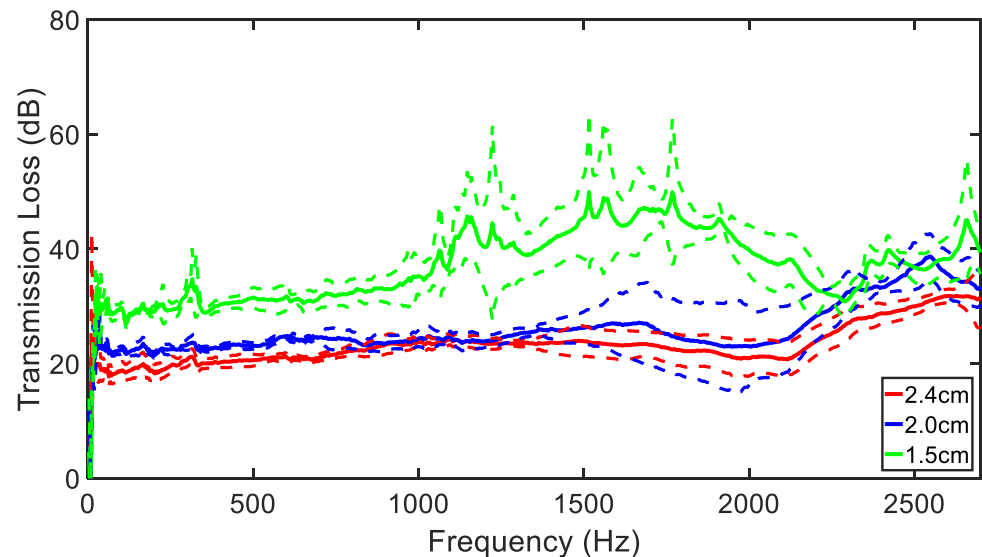


Corrected average transmission loss for seal B with standard deviations from 10 trials at each compression

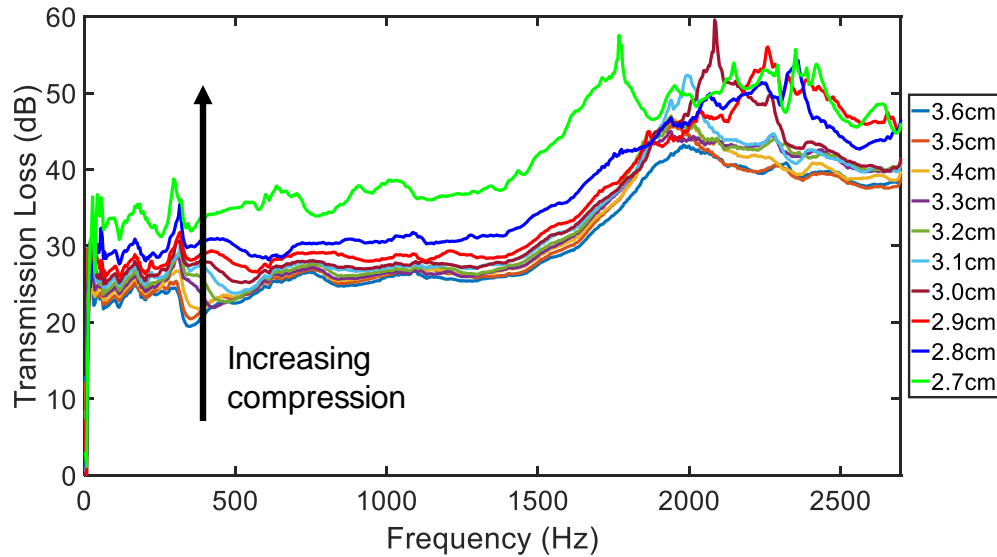


Seal B

- Note apparent shift of TL peak to lower frequencies as compression increases
- TL is similar at low compression with sudden increase at high compression

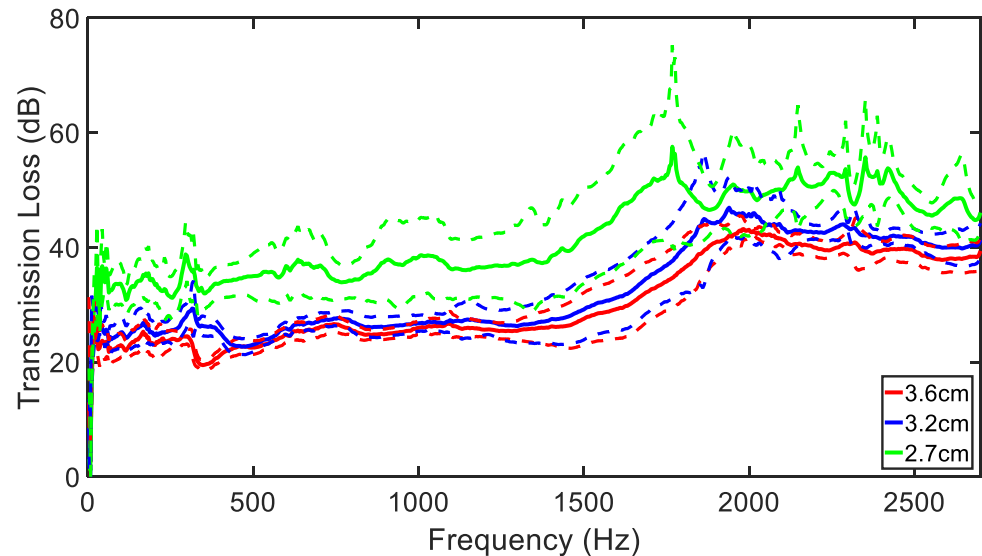


Corrected average transmission loss for seal C with standard deviations from 10 trials at each compression

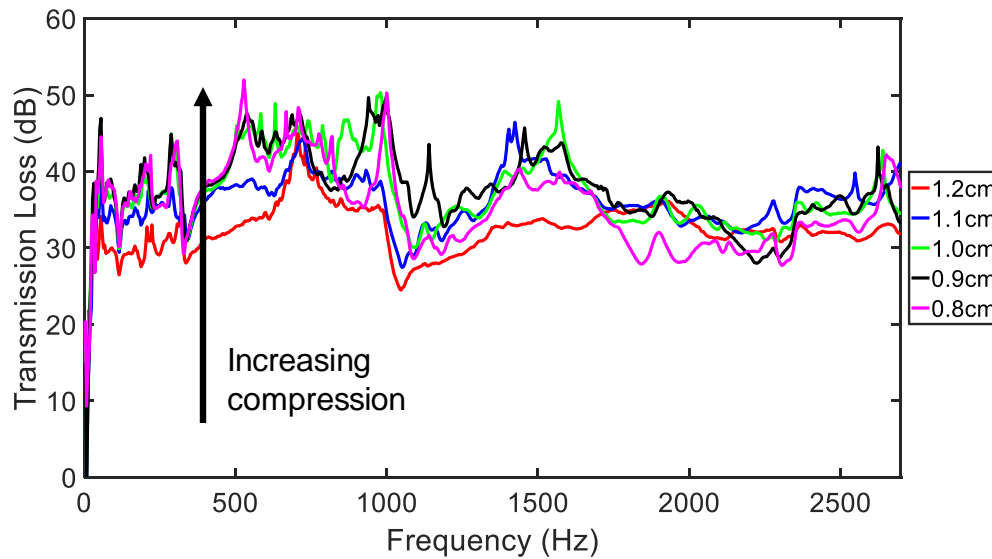


Seal C

- Shift of TL peak to lower frequencies as compression increases
- TL is similar at low compression but increases at high compression

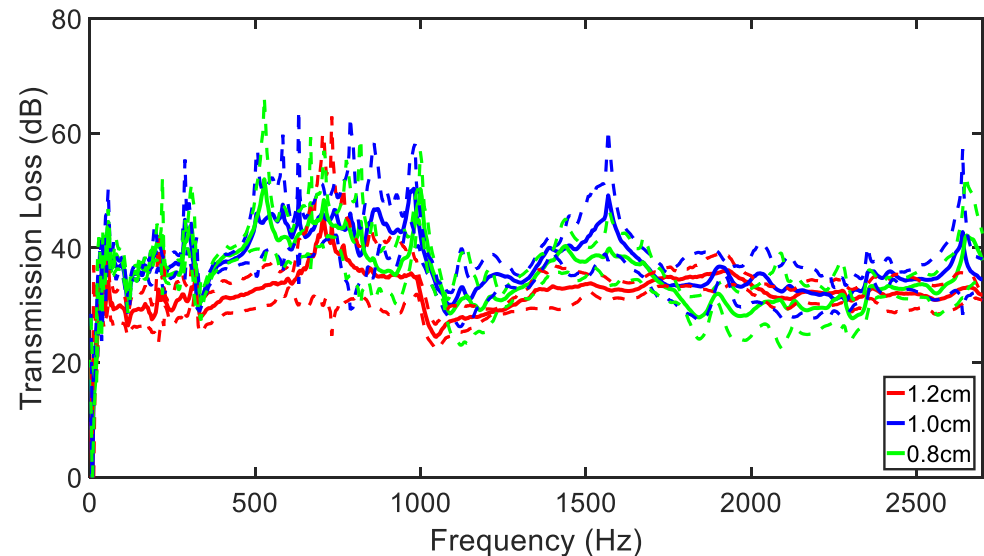


Corrected average transmission loss for seal D with standard deviations from 10 trials at each compression

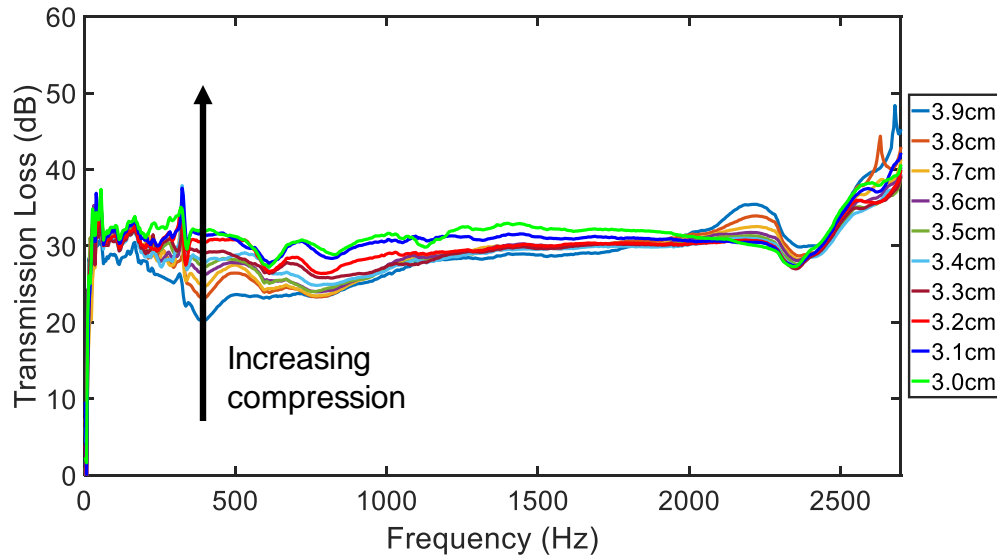


Seal D

- Relatively large scatter for this case
- Effect of compression is small due to limited compression capability

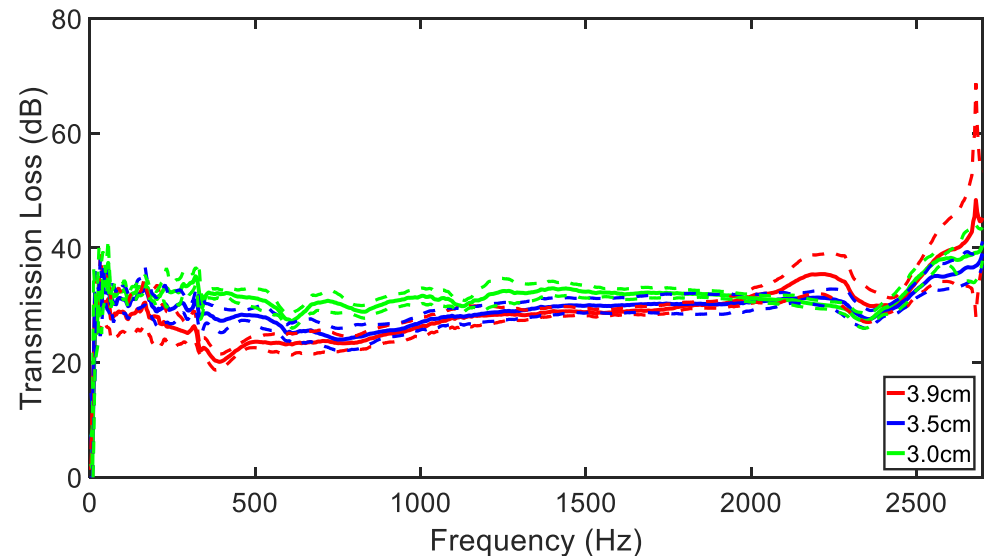


Corrected average transmission loss for seal E with standard deviations from 10 trials at each compression



Seal E

- Very consistent results
- Effect of compression is very small
- TL almost independent of compression



A desktop procedure for measuring the acoustic properties of automotive door sealing systems was described.

- The procedure described could replace the previously conventional method that made use of reverberation chambers.
- It was observed that the transmission loss of the seals progressively increased with increasing compression and the stiffening effect of compression caused some features to shift to lower frequencies.
- A modified clamp system that more accurately represents the way the seals are held in practice should be the next step of the research to increase the utility of this procedure.
- Better to use “reference” materials having TL’s closer to samples.

Acknowledgements

- Our thanks to Ford Motor Company, and in particular, John Nalevanko, for supporting this research, to Caleb Wagner for designing and fabricating the sample holder, and to the 3M Company for providing the square-section standing wave tube.

References

- Robert J. Danforth III and Luc Mongeau, "Sound transmission through road vehicle primary bulb seal assemblies," Herrick Labs report *HL 96-14 Report #3086-2*, December 1996.
- Junhong Park and Luc Mongeau, "Effects of mechanical properties of sealing systems on aerodynamic noise generation inside vehicles," Herrick Labs report *HL 2002-1*, May 2002.
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- Bryan H. Song and J. Stuart Bolton, "A transfer-matrix approach for estimating the characteristic impedance and wave numbers of limp and rigid porous materials," *Journal of the Acoustical Society of America*, Vol. 107, 1131-1152, 2000.
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